

## NEW SCALING LAWS FOR SPACECRAFT DISCHARGE PULSES

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Existing scaling laws for discharge pulses were developed nearly twenty years ago and are based on a small set of laboratory test results. In those tests, samples were exposed typically to 20 keV electron beams of fairly high intensity. A few cases used mixed spectra of 20 keV electrons and higher energy electrons from radioactive sources. The sample thicknesses were of the order 100 micrometers, sometimes less. The samples were planar with only one grounded metalization on the rear surface. The resulting pulses were consistent enough that scaling laws could be developed. Recent extended tests under the NASA-MSFC SEE Program indicate that those scaling laws are a subset of a more general set of scaling laws. In addition, different scaling laws are now indicated to describe how the pulse current partitions onto several sensitive nodes. Additionally, new scaling laws are now available for differing load resistors.

The earlier scaling laws were essentially a result of the following narrow conditions and the resulting consistent discharge phenomena. The dielectric samples were strongly stressed with order 10 kV across order 100 microns producing internal electric field of order  $1\text{E}6$  V/cm. The resulting pulses produced scaling laws which can succinctly be described as having triangular shape in  $I(t)$  with consistent slew rate, and always discharging more than half the original surface voltage over the entire sample area. In contrast, tests which provide more realistic space-like charging conditions produce a wide variety of scaling laws.

The new results find that the electric field inside the insulator is a critical term in controlling the pulse. In space, internal electric fields are closer to  $1\text{E}5$  V/cm. Once the potential differences on surfaces in the vacuum achieve a kilovolt or so, the field inside the insulator becomes a major controlling term. In addition, the divergence of the electric field in the vacuum becomes important. Further, the arrangements of other surfaces and their impedance to ground strongly affects the current pulse to any particular electrode. These effects are controlled by the evolution of the Townsend gas avalanche in the vacuum space after the partial discharge tree in/on the insulator injects a pulse of gas into the vacuum space. The evolution of gas is strongly dependent on the electric field in the insulator.

Briefly stated, the newer more complete list of scaling laws now includes:

1. The original scaling laws still hold for both planar geometry and divergent geometry when the insulator has internal fields in excess of  $1\text{E}6$  V/cm, and thereby large surfaces are nearly fully discharged.
2. Confining the movement of neutral gas within the electric field region enhances the conductance of the discharge.
3. Divergent electric field in the vacuum space enhances the pulsed current amplitude relative to planar field of the same field strength.

4. The pulse rate is roughly proportional to the internal dielectric field-strength raised to a (unknown) positive power. It goes to zero somewhat below  $1E5$  V/cm.
5. The quantity of gas injected, and therefore its ability to discharge surface area, decreases strongly as internal electric field decreases and goes to zero somewhat below  $1E5$  V/cm. The peak current, total charge, and pulse energy similarly decrease.
6. Combining 4 and 5 one determines that, by any cause on a particular sample, decreasing pulse rates are associated with decreasing charge and energy in the associated pulses.
7. If the ionized gas current flows to more than one electrode, because the gas is diffuse it will roughly spread to electrodes proportional to their area, except when .....
8. Divergent electric fields and material surfaces modify the flow of the gaseous discharge current and must be considered in order to estimate its amplitude.
9. One determines the pulsed voltage,  $V(t)$ , on the load resistor,  $R_L$ , such that the current,  $I(t)$ , through the load resistor in series with the impedance of the gas discharge,  $R_G(t)$ , equals the time dependent surface voltage,  $V_S(t)$ . Thus,  $V(t)=I(t) \times R_L$  where  $V_S(t)=I(t) \times [R_L + R_G(t)]$ .

**keywords:** spacecraft charging, spacecraft discharge, scaling laws, discharge pulse amplitude, dielectric discharge, partial discharge